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By

John Ehrlich

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A PRELIMINARY STUDY OF ROOT DISEASES IN WESTERN WHITE PINE 1/

By

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For many years various individuals have made scattered observations on the existence of root diseases in western white pine (Pinus monticola) and associated species of all ages, and the impression has grown that these diseases may influence the future management of western white pine. Lacking definite information on the incidence, importance, and identity of these diseases, and on their possible relation to site, weather, or mountain-pine-beetle (Dendroctonus monticolae) attacks, a preliminary investigation was undertaken in the summer of 1938.

Purposes were to: (1) develop a tentative field procedure suited to discovery of root diseases in extensive tree examinations; (2) learn to diagnose the root diseases in the field; (3) obtain, by preliminary extensive tree examinations in selected drainages, information on root diseases regarding prevalence, possible relation to site and tree age, external symptoms in relation to degree of infection, and the value of symptoms in extensive tree examinations; (4) determine whether there is a relation between root diseases and infestation by the mountain pine beetle.

Work was restricted to western white pine in certain areas on the Coeur d'Alene National Forest, Idaho. Except for beetle-killed trees, examination was limited to individuals in the upper crown story (dominant and codominant). These trees were examined for evidence of root diseases, and the associated fungi were isolated and cultured. Only diseases beginning in the bark and outer sapwood were studied.

1/ A cooperative project of the Northern Rocky Mountain Forest & Range Experiment Station, the Forest Insect Laboratory at Coeur d'Alene, and the University of Idaho School of Forestry. It was planned by Kenneth P. Davis, James C. Evenden, and the author, and carried out by Charles A. Wellner, W. D. Bedard, and the author, assisted by Loren K. Baker, William B. Petersen, T. T. Terrell, Stewart E. Brown, George R. Fahnestock, and CCC enrollees. This paper is condensed from an experiment station office report entitled "A Preliminary Study of Root Diseases in the Western White Pine Type", June 20, 1939. (A copy of this report may be borrowed on application to the author, School of Forestry, Moscow, Idaho, or to the Northern Rocky Mountain Forest & Range Experiment Station.)

Activities during July consisted of intensive field examination of infected trees, and laboratory isolation, pure culture, and attempted identification of the associated fungi. These activities were conducted in fulfillment of purposes 1 and 2. During August and early September the field procedure developed was employed in preliminary extensive tree examinations in two drainages, in fulfillment of purpose 3. Beginning in late June and continuing into early September, similar examinations were made of bettle-attacked trees, in fulfillment of purpose 4.

INTENSIVE TREE EXAMINATION

A preliminary field examination of the roots of infected trees was deemed desirable as a background for methods and techniques to be used in this study. Four areas were studied which appeared to be centers of root diseases. These were in 10-20, 41-60, 61-80, and 161-200 year age classes. Roots of 27 trees were examined by baring the roots, peeling their bark, and recording detailed observations. A tree bared for examination is shown in plate 1-B.

The results of the examination showed that: an examination confined to the root surfaces adjacent to the root collar would not disclose the presence of all infection since infection apparently may start at any point on the root surface; the appearance of the crown may be a good indicator of the seriousness of infection; the rapidity of fungal activity varies greatly; rhizormorphs are abundant in the soil of the white pine type; measurements of the annual rings above infected and uninfected lateral roots yield worthwhile information on the duration of serious infection.

CULTURE OF ASSOCIATED FUNGI

Since it was found difficult at the start to distinguish between the diseases on the basis of their symptomatology, it was decided to attempt the isolation of the associated fungi from the roots of a number of the intensively examined trees. Approximately half of the attempted sets of isolations from mycelial fans and infected sapwood were successful and of 52 separate isolates, 31 represented Armillaria mellea, 10 Fomes annosus, and 11 unidentified fungi. None of the attempted isolations from rhizomorphs proved successful. Fruiting bodies of A. mellea are shown in plate 1-A.

EXTENSIVE TREE EXAMINATION

The exploratory work in field and laboratory had shown that a relatively rapid tree-examination procedure could be expected to disclose advanced infection in the root collar and, in most cases, permit its diagnosis. Since information was lacking on the rate of spread of infection in the individual tree and the possible influence of site and tree vigor upon this rate, precise data on incidence of infection could have but little meaning. Information on the incidence of infection so advanced that it could be presumed to be retarding increment appreciably and dooming the tree to early death was deemed of significance, however. Because a relatively rapid tree-examination procedure

could yield such information, it was decided to test its usefulness by making a preliminary extensive tree examination.

Since the work of this first season was regarded as preliminary and had for its broad objective an evaluation of the problems and possible methods of approach, it was decided to make these examinations in two readily accessible areas of known decadence, a 161-200 year old stand on the south-facing head of Hoodoo Creek, a tributary of east-facing Deception Creek within the Deception Creek Experimental Forest; and a 101-140 year old stand in the southwest-facing upper reaches of Clay Creek about 13 miles distant, a tributary of south-facing Steamboat Creek, Coeur d'Alene National Forest. Timber volumes of these stands averaged about 25,000 board feet per acre. Topography of both areas is steep, slopes ranging from 15 to 60 percent.

Western white pine trees on the two areas were sampled by arbitrarily located lines running as nearly as possible at right angles to the contours. Along these lines, one tree every chain (66 feet) was chosen for examination, the chosen tree being the dominant or codominant individual closest to the chain mark and within a radius of half a chain. If no suitable tree stood within this radius, a tree was chosen a chain farther along the line. On the two areas, 180 trees were examined along 11 lines.

Preparation consisted in digging away enough soil to bare the root collar and every lateral root within 2 feet of the root collar and not more than about 1 foot below the ground line. Sufficient bark was removed to observe the character and extent of infection in the inner bark, cambium, and sapwood (plate 1-C). With an increment borer, two cores at least 3 inches long were taken from the bole of each infected tree at a point approximately 1 foot above the ground line. One of these cores was taken above the root with greatest percentage of bared surface infected, and the other above the root showing the least infection or one without infection. Each main lateral root was separately numbered and described and the cores were indelibly marked with numbers corresponding to the tree and root numbers.

Results and Conclusions

1. Prevalence of Root Diseases

One ultimate objective of an extended investigation of root diseases is, of course, an evaluation of their role in the decadence of merchantable stands and the formulation of rules for economically feasible control through modifications of forest practice. Before their role can be evaluated, it must be ascertained whether they are capable of killing sound trees, whether they merely hasten the death of trees weakened or retarded by other agencies, or whether they are merely accompaniments of death due to other causes. The preliminary investigation of 1938 was not expected to supply the answer to this question, but to furnish information suggestive of the answer. Of first interest is the prevalence of root diseases as indicated by incidence and cause, degree, and duration of root infection.

Incidence and presumed cause of infection. Table 1 shows that 59 percent of all trees examined were infected in the root collar and in the

Table 1.-- Incidence and presumed cause of root infection in western white pine trees.

Drainage	Trees examined	Trees infected		Presumed cause of infection 1/		
				Armillaria mellea	Fomes annosus	Unknown species
	Number	No.	Pct.	Percent	Percent	Percent
Hoodoo	86	49	57	84	14	10
Clay	94	57	61	86	12	12
Total or average	180	106	59	85	13	11

1/ These figures total more than 100 percent because certain trees were infected by more than one species of fungus.

proximally bared portions of the main lateral roots. It is noteworthy that 85 percent of the infected trees showed evidence of infection by Armillaria mellea and only 13 percent by Fomes annosus. In interpretation, it must be borne in mind that the estimate of incidence of infection is conservative because only those trees which showed infection in the bared portions of the root system were recorded as infected, whereas the preliminary intensive tree examinations had demonstrated that infection may begin in other parts of the root system as well. On the other hand, these figures do not disclose the relative degree of infection in the trees recorded as infected and hence may lead to an exaggerated impression of the importance of root infection in the drainages sampled. It is also noteworthy that there is close agreement between the two drainages both in incidence of infection and in presumed cause of infection, but this is perhaps not as remarkable as it might appear because both are southerly drainages and both were known in advance of examination to contain a large proportion of infected trees.

Degree of infection. Since the data shown in table 1 do not disclose the degree of infection, the infected trees were grouped in classes based on the fraction of the circumference of root collar killed. This fraction was estimated in the field for each tree. Table 2 gives results of this grouping. Although 59 percent of the trees showed root infection in the portions examined, only 16 percent of the trees had half or more of the circumference of the root collar killed and might therefore be regarded as doomed to death in the near future. Again it is noteworthy that the percent of trees in each infection class in the two drainages is close.

Table 2.-- Degree of root infection in western white pine trees.

Drainage	Trees examined	Uninfected trees	Infected trees, grouped by fraction of circumference of root collar killed					Total
			Under 1/4	1/4	2/4	3/4	4/4	
	Number	Pct.	Percent	Percent	Percent	Percent	Percent	Percent
Hoodoo	86	43	29	12	11	5	0	100
Clay	94	39	33	12	8	6	2	100

Duration of infection. Even though it is not yet known whether Armillaria mellea (and other associated fungi) are causes or merely concomitants of decadence, the ability to estimate duration of infection in individual trees on the basis of the appearance of the affected roots would be of great value in predicting loss and in its prevention through intelligent marking and timely utilization. It was assumed that severe infection of any main lateral root would retard cambial activity in the trunk immediately above it. It was therefore thought that measurement of the width of recent annual growth rings in the wood might show a recent decrease and that numerous measurements might thus provide an indirect measure of the duration of infection sufficiently severe to influence cambial activity and thus increment. Accordingly, the increment cores, taken as described, above the most infected and the least infected (or an uninfected) root were measured and analyzed by 5-year periods. A stump section of a tree so analyzed is shown in plate 1-D.

The results, which are given in figure 1, disclose that with 0 to 25 percent of the bared surface infected no appreciable reduction in increment occurred. With 26 to 50 percent infected, increment was significantly reduced for 15 years prior to examination but not for the period 16 to 25 years before examination. Considered with the 0-25 percent class, this seems to indicate that infection is responsible for reduction in increment only when it reaches a certain extent--probably something over 25 percent as judged from these data. Where more than 50 percent of the bared surface was infected, increment was consistently reduced for the full period examined--25 years--indicating that such trees have been infected at least that long. In general, the data show that infection is of long standing and, with increasing extent, causes increasing reduction in increment.

2. Factors Possibly Influencing Root Diseases

Of a number of factors that might influence the incidence of infection, the data on incidence were analyzed only as related to site quality, tree height, site moisture, and proximity of snags and stumps. The results of tabulating incidence of infection in each of three site-quality classes indicate that infection is more frequent on poor sites than on fair and good sites, suggesting that, quite apart from the possible influence of site upon the fungi, trees growing on good sites are better able to resist infection.

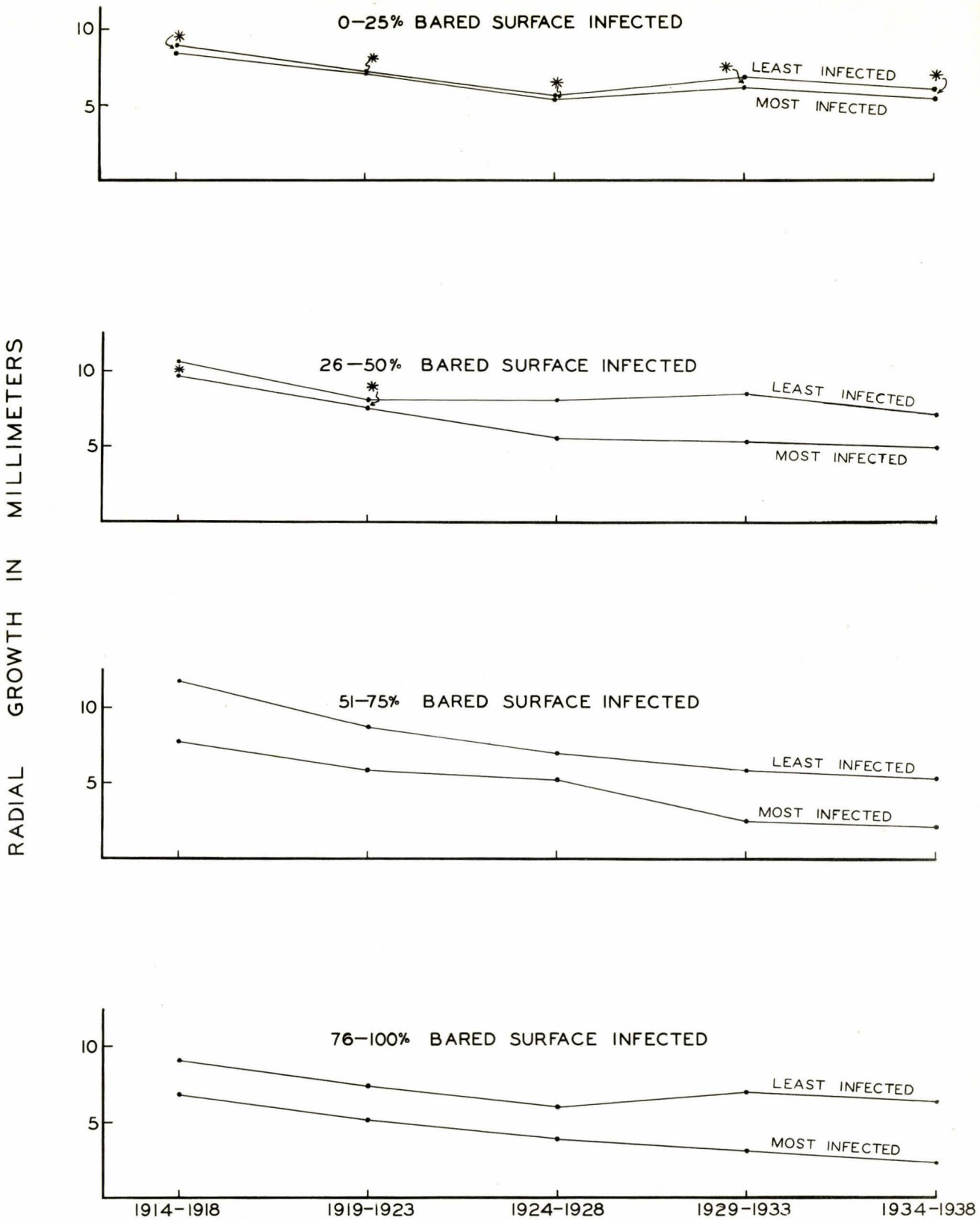

FIGURE 1.— RELATION OF DEGREE OF INFECTION TO RADIAL INCREMENT BY FIVE YEAR PERIODS

When the incidence of infection was tabulated on the basis of tree height it was found that comparable results were obtained; that is, a large percent of the trees in the shortest height class was infected and a much smaller percent of the trees in the tallest height class was infected. Since the trees in each drainage were all in the same age class, and all dominant or codominant, height may be regarded as a rough measure of vigor. The data thus indicate that slower growing trees are less resistant to infection than vigorous trees. The results of tabulating incidence of infection in each of three site-moisture classes seemed to indicate that on wet sites (close to the stream) trees are less subject to infection than on moist and dry sites. Since the areas sampled are all steep, well-drained, and in a region of only moderate rainfall, it is assumed that moisture is favorable to the tree, increasing its vigor and thus its resistance to infection. The influence of site upon the fungi on these areas is not known. Because Armillaria mellea is known to live saprophytically on the roots of snags and stumps and to send rhizomorphs radiately to nearby trees, it was thought that there might be a relationship between the number of snags and stumps in the vicinity of individual trees and the incidence of infection, but the results of analysis indicate no significant relationship.

3. Relation of External Symptoms to Degree of Infection

The most obvious external symptoms of unhealth which might result from root infection are color of foliage and density of crown. Accordingly, the data on degree of infection were tabulated to bring out any connection which there might be between degree of root infection and development of these symptoms. The results are given graphically in figure 2.

Color of foliage is apparently strongly related to degree of root infection (figure 2A). Of the trees without disclosed root infection, 97 percent had healthy green foliage and none had appreciable quantities of brown foliage. At the other extreme, none of the trees with more than half of the circumference of root collar killed had healthy green foliage, and the trees in which the root collar had been completely killed (only two in this class) had mostly brown foliage.

Degree of root infection is also fairly well reflected in density of crown (figure 2B). Of the trees without disclosed root infection, 82 percent had dense to medium crowns and both of the trees in which the whole of the root collar was killed had ragged crowns. However, the fact that 18 percent of the trees without disclosed infection had open or ragged crowns indicates that density of crown is not a completely reliable indication of root infection.

4. Value of Symptoms in Extensive Tree Examinations

Having recorded certain external and internal symptoms of root infection, it seemed desirable to determine how far the readily determinable symptoms could be relied upon to furnish an indication of the degree of root infection. In conformity with results above, color of foliage was found to furnish a moderately reliable measure of degree of root infection, although it was not a dependable criterion of absolute infection. Density of crown

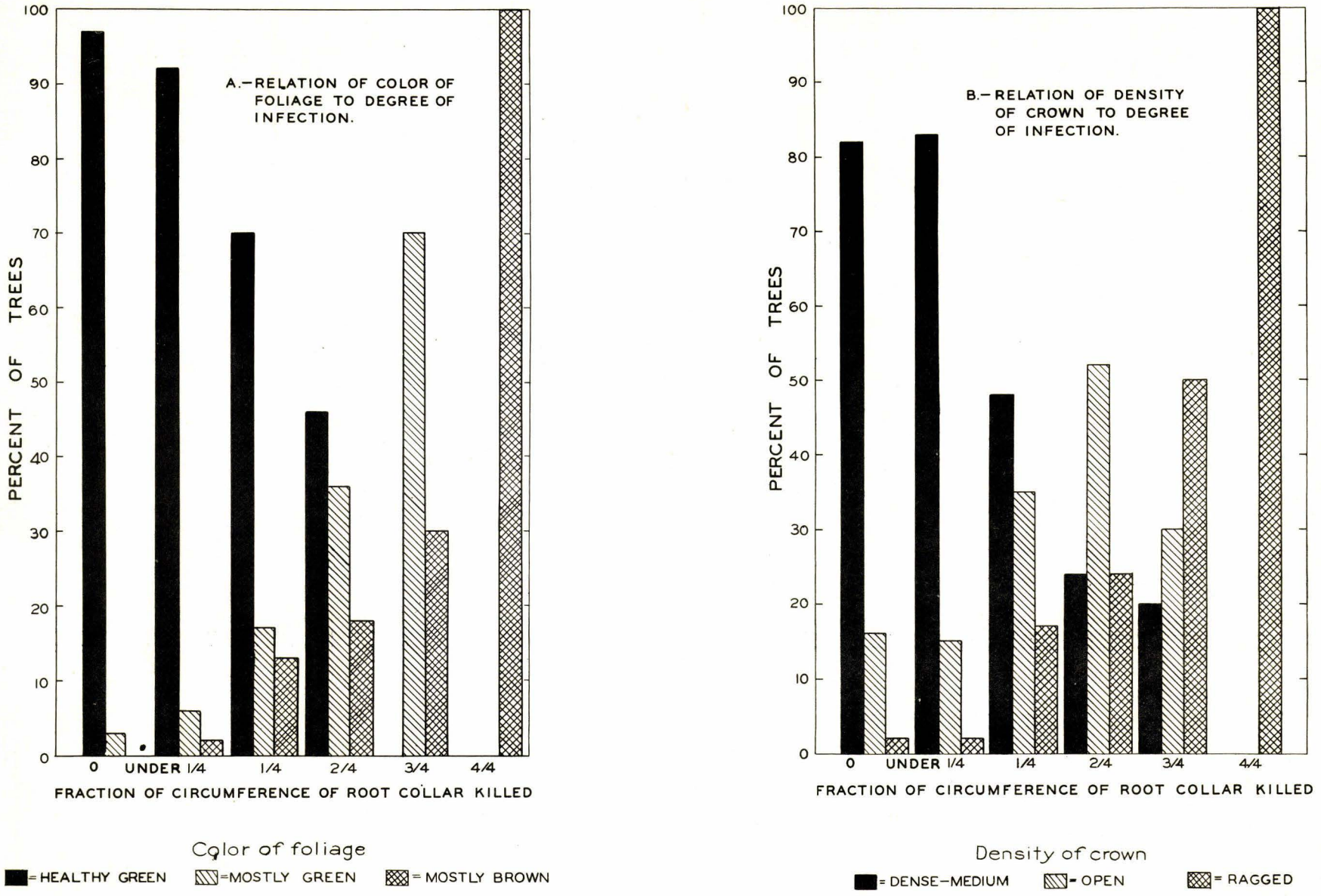

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FIGURE 2.— RELATION OF DENSITY OF CROWN AND COLOR OF FOLIAGE TO DEGREE OF INFECTION

s found to furnish an only slightly reliable measure of degree of root infection and is not a dependable criterion of absolute infection.

Further extensive tree examinations to determine incidence of infection as related to site or other factors could be made more rapidly and with less injury to the examined trees if degree of root infection could be determined without baring the roots as thoroughly as had been deemed necessary in the 1938 examinations. It was thought that there might be a direct relationship between the degree of root infection in the root collar and the height of infection on the stump. If this relationship were found to exist, degree of root infection could then be estimated merely by determining the maximum height of infection without the necessity of baring the root collar. Accordingly, the possible degree of such relationship was investigated by correlating maximum height of infection (measuring from the ground line) as the dependent variable, with the fraction of circumference of root collar killed as the independent variable. The correlation was so poor that it was obvious that height of infection can not be used to estimate degree of root infection with useful accuracy. A scatter diagram plotted from these data does show, however, that infection seldom reaches the ground line until more than one quarter of the circumference of the root collar has been killed. This means that if the objective of extensive tree examination were merely to determine the number of trees with more than one quarter of the circumference of root collar killed, it would be necessary merely to examine the trunk at ground line.

RELATION TO BEETLE ATTACK

It has long been suspected that root infection may predispose trees to attack by the mountain pine beetle even though it is known that the beetle is capable of killing healthy trees. If this suspicion could be verified, attack of infected trees by the beetle would be the immediate cause of death, but the initial cause would have to be sought either in previous infection by root-attacking fungi or in circumstances leading to such infection. Investigation of this point was made by examining the root systems of a number of beetle-attacked trees to determine whether insect or fungus came first, and to compare the incidence and degree of infection in beetle-attacked trees with incidence and degree in line trees.

These root examinations of beetle-attacked trees were made by the Coeur d'Alene Forest Insect Laboratory, Bureau of Entomology and Plant Quarantine, as a supplemental part of regular infestation studies made in 1938 in the Deception, Yellow Dog, and Kelley Creek drainages within the Coeur d'Alene National Forest. On these areas root examinations were made on as many of the trees being examined by the infestation study crew as time permitted. Of 92 trees examined, 58 had been attacked by the mountain pine beetle in 1937, and 34 in 1938. The method of root examination of the beetle-attacked trees was similar to that of the trees studied in the extensive tree examinations.

Results and Conclusions

1. Prevalence of Root Diseases

In the examination of beetle-attacked trees, only visible root infection diagnosed as the work of Armillaria mellea was recorded because of inability to determine other causes of infection when the work was begun. Because the results of line-tree examinations had shown Armillaria mellea to be the main cause of infection, the absence of data on other causes of root infection in the beetle-attacked trees should not gravely impair the value of the data. Data given in table 3 on incidence of infection by Armillaria mellea in trees attacked by the mountain pine beetle show that of the trees examined in four

Table 3.-- Incidence and degree of infection by Armillaria mellea in the roots of beetle-attacked western white pine trees.

Year of beetle attack	Drainage	Trees examined	Uninfected trees	Infected trees, grouped by fraction of circumference of root collar killed					Total
				Under 1/4	1/4	2/4	3/4	4/4	
		Number	Percent	Percent	Percent	Percent	Percent	Percent	Percent
1938	Deception	23	61	17	9	0	4	9	100
	Kelley	11	36	37	9	0	0	18	100
	Both drainages	34	53	23	9	0	3	12	100
1937	Deception	42	31	31	7	10	7	14	100
	Kelley & Yellow Dog	16	0	19	31	6	31	13	100
	Both drainages	58	22	27	14	9	14	14	100
Both years	All drainages	92	34	26	12	5	10	13	100

drainages, 47 percent of the trees attacked by beetles in 1938 were infected as compared with 78 percent of the trees attacked in 1937. These figures cannot, however, be unqualifiedly compared with the incidence figures for the trees examined on arbitrarily located lines, because not all trees were in the same drainages and because many of them had been dead for a year. Averaging all drainages and both years, the incidence of infection for beetle-attacked trees was approximately 7 percent greater than for the line trees. But for the trees attacked by the beetle in 1938, which are roughly comparable with the

line trees, incidence of infection was actually approximately 12 percent less than for the line trees. Even for trees attacked by the beetle in 1937, in which a whole year had elapsed during which fungal infection might be presumed to have increased and extended rapidly, incidence of infection was only 19 percent greater than for the line trees. These results give no indication that root infection increases the likelihood of beetle attack.

The results further indicate that infection may take place and spread rapidly following beetle attack. This possibility is supported by observation of extensive, apparently fresh, mycelial fans under the bark in aboveground parts of dying beetle-attacked trees. Of the 1938-attacked trees, 13 percent on Deception Creek and 18 percent on Kelley Creek had half or more than half of the circumference of root collar killed by root infection. For the 1937-attacked trees, the figures are 31 and 50 percent, respectively. The 1938-attacked trees on all the areas appear to be comparable with the line trees, of which 16 percent had half or more of the circumference killed. As might be expected, degree of root infection parallels incidence of infection, being greater a year after beetle attack than in the same season.

2. Relation to Possibly Influencing Factors

Since the number of infected trees examined was small, especially those attacked by the beetle in 1938, trees examined in all drainages were combined by years of beetle attack, and incidence of infection was determined for different classes of site quality, tree height, site moisture, and aspect. The results of tabulating incidence of infection in each of three site-quality classes substantiate the results with line trees and indicate that infection is more frequent on poorer sites than on good sites. As might be expected, incidence is higher in trees attacked in 1937 than in 1938 for all site classes, but the relationship is similar for both groups of trees. When incidence of infection was tabulated on the basis of tree height, comparable results were obtained and the results with the line trees were substantiated. The results of tabulating incidence of infection in each of three site-moisture classes indicate that the trees attacked by the beetle in 1938 substantiate the results with line trees and show that on wet sites trees are less subject to infection than on drier sites. The results with trees attacked by the beetle in 1937 appear to be opposite but are probably indeterminate. Since the beetle-attacked trees covered a wider range of aspects than did the line trees, an analysis was made to see if they might give an indication of a possible relationship between incidence of infection and aspect. The results were inconclusive, however, save to suggest that, as might be expected, incidence of infection is somewhat greater on the drier aspects (west, south, and ridge top) than on the wetter aspects (bottom, north, and east).

CONCLUSIONS

The results of the season's work lead to the following conclusions. In the areas sampled, root diseases are common in mature western white pine, the most common being shoestring root rot caused by Armillaria mellea, a fungus which is apparently a widespread saprophyte in the soils of the western white pine type. Since evidence of root infection by this fungus can be found in apparently healthy trees as well as in obviously unhealthy and dying trees, and since increment reductions attributable to infection have occurred for many years, it must be concluded that infection is of long standing in certain trees.

The precise role of root diseases, especially shoestring root rot, in the decadence of mature pine stands, is as yet uncertain. Whatever their role may be, and whatever the role of endemic infestation of the mountain pine beetle may be, it appears unlikely (but not impossible) from the meager data at hand that root diseases increase the probability of attack and death by the mountain pine beetle.

Specific information is still lacking on (1) the prevalence of root diseases in mature western white pine on different sites; (2) the relation of tree age and method of stand establishment to susceptibility; (3) the relative aggressiveness and virulence of existent strains of Armillaria mellea and other root pathogens; (4) the effects of individual site factors on resistance of the tree and aggressiveness of the fungi; (5) the influence of root infection on beetle attack; and (6) the relative susceptibility of the different tree species which composes the western white pine type. Information on these questions would assist in the intelligent formulation of practical recommendations for the reduction of losses in the remaining virgin stands as well as in the managed stands of the immediate future.

Photo by H. M. Cowling,
Bur. Ent. & Plant Quarantine

A. Fruiting bodies of Armillaria mellea.

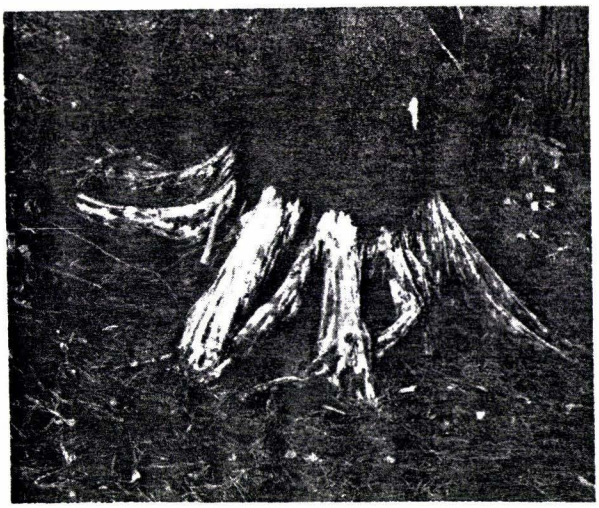

Photo by H. M. Cowling,
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C. Base of western white pine tree in Hoodoo Creek bared and partially barked for extensive examination of live trees. Much less excavating was done than as illustrated in B for trees intensively examined in the first part of the season.

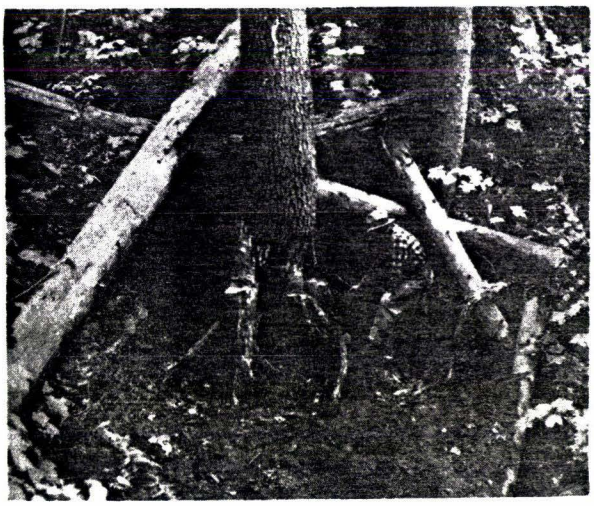

Photo by H. M. Cowling,
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B. Base and proximal root system of western white pine tree bared for intensive examination.

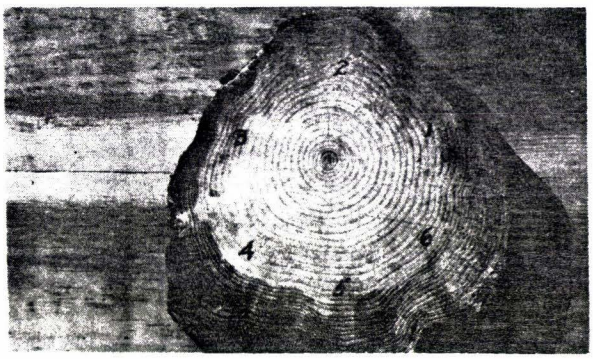

Photo by C. A. Wellner, U.S.F.S.

D. Stump section of western white pine tree showing reduction of diameter increment caused by Armillaria mellea. Roots 1, 2, and 3 were heavily infected.

PLATE 1.